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Influence of pilot scale in pack pasteurization and sterilization treatments on nutritional and textural characteristics of carrot pieces

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ABSTRACT

The current work presents a pilot scale study in which the effect of in pack thermal preservation processes in a retort system on particular carrot quality aspects, more specifically nutritional and textural characteristics, was investigated. Pasteurization as well as sterilization processes with different intensities were included. The carrot hardness, analyzed by a compression test, and the β-carotene bio-accessibility, analyzed by an *in vitro* digestion method, were the main quality markers. As a main conclusion, it can be stated that the results of this pilot scale study are a good validation of results obtained during previous laboratory scale experiments on carrot nutritional and textural characteristics. The processes applied in this study only resulted in limited conversion of all-trans-β-carotene to its cis-isomers. Furthermore, it was shown that intense thermal processing is required to observe a significant increase in the β-carotene bio-accessibility. However, this was accompanied with a clear degradation of the hardness. When thermal processing was preceded by low temperature blanching, a technique to improve texture retention of thermally processed plant-based foods, a lower β-carotene bio-accessibility was observed. Both observations clearly illustrated the inverse correlation between textural and nutritional characteristics of (processed) carrots. Statistical analyses confirmed the trends observed. For process design, the choice of the process intensity was identified to be crucial: the required product safety needs to be achieved, while still reaching an acceptable structural and nutritional quality. Exploring strategies to enhance the β-carotene bio-accessibility while ensuring an acceptable carrot texture can therefore be useful.

1. Introduction

Thermal processing is a widely used technique for the preservation of food products (Richardson, 2001). Considering the application of heat to the food product, thermal preservation processes can be classified into two main groups based on their intensity: pasteurization and sterilization processes. Each of the processes has its own specificity (such as the process intensity, the applicability to certain products *etc.*) resulting in a typical shelf life of the food product (Ramaswamy & Marcotte, 2006; Silva & Gibbs, 2009; Holdsworth, 2009). Next to the intended effects on pathogenic and spoilage micro-organisms and deteriorative enzymes, it is known that thermal processing affects food quality (Holdsworth, 2004). The process intensity partially determines to which extent food quality is influenced (Ramaswamy & Marcotte, 2006). Depending on the quality attribute of interest, thermal processing of food products can result in a loss or an improvement of the food quality (Arnoldi, 2001). Optimal process and product factors need to be identified in order to diminish the undesired quality losses and to maximize the desired quality improvement as much as possible, while still ensuring microbial safety (Holdsworth, 2004). Numerous studies at laboratory scale have been performed on the effect of thermal processing on specific quality attributes of fruit and vegetable based food products. However, to facilitate the transfer of this knowledge to or the application of this knowledge by industry, it is essential to carry out pilot scale validation studies.

Carrots are a good source of β-carotene (Krinsky & Johnson, 2005). Due to specific properties of β-carotene (*i.e.* anti-oxidative properties and provitamin activity), its consumption or the consumption of fruit and vegetables rich in β-carotene has been associated with particular human health benefits such as normal growth and development and a reduced risk for some cancers and cardiovascular diseases (Paiva and Russell, 1999; Stahl and Sies, 2005). However, it should be noted that, although animal studies as well as epidemiological studies, support this hypothesis, the results of large scale clinical studies using high doses of β-carotene supplements are not always unambiguous. It is clear that more research in this context is required (Woutersen et al., 1999). To get an estimation of the nutritional value of food products, Fernández-García, Carvajal-Lérida and Pérez-Gálvez (2009) stressed the necessity of investigating to which extent nutrients can be

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digested (bio-accessibility) and can effectively be absorbed to carry out their function in the human body (bio-availability). In the case of carrots, it is thus relevant to study the β-carotene bio-accessibility, as an indication for the β-carotene bio-availability. In the context of thermal processing, laboratory scale studies suggested a desirable effect of thermal processing on the β-carotene bio-accessibility (*e.g.* Hedrén, Diaz & Svanberg, 2002; Veda, Kamath, Platel, Begum & Srinivasan, 2006; Hornero-Mendez & Mínguez-Mosquera, 2007; Lemmens, Van Buggenhout, et al., 2009; Aherne, Daly, Jiwan, O'Sullivan & O'Brien, 2010). On the other hand, it should be kept in mind that β-carotene is susceptible to oxidation and isomerization reactions during thermal processing due to its typical chemical structure (Rodriguez-Amaya, 1999). This dual effect of thermal processing on the β-carotene content and bio-accessibility was recently highlighted by Maiani et al. (2009).

It is well-known that texture is another important quality attribute of carrots, which is mainly determined by the structural characteristics of the carrot tissue (Waldron, 2004). Since it is generally accepted that thermal processing has an effect on the structural characteristics of fruit and vegetable tissues, thermal processing can be used as a tool to influence the carrot texture (Sila, Smout, Elliot, Van Loey & Hendrickx, 2006). Depending on the intended use of the processed carrots, a specific texture (hardness) is aimed for and hence, this determines whether the effect of thermal processing on the carrot texture is (un)desirable.

This pilot scale case study on carrots mainly concentrated on the recently highlighted importance of the relation between food structure and nutrient bio-accessibility and bio-availability (Waldron, Parker & Smith, 2003; Parada & Aguilera, 2007). Results of our previous studies on laboratory scale (Lemmens, Van Buggenhout, et al., 2009; Lemmens, De Vleeschouwer, Moelants, Colle, Van Loey & Hendrickx, 2010) were validated in a detailed way, covering a wide range of industrially relevant processing conditions, *i.e.* pasteurization and sterilization intensities, and focusing on important quality attributes of carrots, *i.e.* the β-carotene concentration, the *in vitro* β-carotene bio-accessibility and the hardness of the carrots. It was investigated to what extent the selected quality attributes were affected by the intensity of in pack thermal processing in a retort system. The experiment was performed on raw as well as on low temperature blanched carrots, since this thermal pretreatment is commonly used in laboratory scale studies.

2. Materials and methods

2.1. Experimental set-up

2.1.1. Carrots

Fresh carrots (*Daucus carota* cv. Nerac) were bought in a local shop in Belgium and stored at 4 °C. The carrots were peeled and cut into calibrated (disks of 10 mm height and 12 mm diameter) and non-calibrated pieces. The calibrated carrot pieces were used for analysis of the nutritional and textural characteristics, whereas the non-calibrated carrot pieces were used as filler material. To perform the pretreatment or the actual thermal treatment, the carrot pieces were packed in respectively firm plastic bags (vacuum packed) or glass jars (370 ml volume, 99 mm height and 80 mm diameter). The glass jars were filled for 190.0 (±0.5) g and depending on the thermal treatment, a specific brine was added (the headspace was set at 5 mm) (Table 1).

2.1.2. Retort

The actual thermal treatments were executed in a pilot water cascading retort system (Barriquand Steriflow retort, Paris, France) equipped with one basket (0.40 × 0.37 × 0.70 m). During the heating and holding phase, the external heat exchanger was supplied with steam, while during the cooling phase, cold water was used. The thermal processes, performed in the retort system, typically consisted of different phases: initially, the retort was heated up until 40 °C, the temperature to which the carrot samples were equilibrated prior to the actual thermal treatment. When the carrot samples reached the equilibration temperature, the retort coming up time (CUT) was programmed at 8.5 min, followed by a holding time at process temperature for a predetermined time interval. Afterwards, the glass jars were gradually cooled (cooling phase).

Table 1
Detailed overview of the different processes, ranked according to their intensity. The pasteurization (process A and B) and sterilization (process C, D, E, F and G) processes were performed on non-pretreated as well as on pretreated carrot pieces. The coming up time was 8.5 min for all processes. $F_0 = {}^{10\,°C}F_{121°C}$; H_2O = deionized water; buffer = 0.1 M sodium acetate-aacetic acid buffer.

	Brine	Process T (°C)	Process time (min)	Targeted P/F_0 value (min)	Achieved P/F_0 value (min)
Process A	H_2O	70	7.5	2	1.85 ± 0.18
Process B	H_2O	90	19.6	10	9.67 ± 0.49
Process C	Buffer pH 4.2	117	11.0	1.2*	1.25 ± 0.08
Process D	Buffer pH 4.9	117	12.7	1.7*	1.45 ± 0.22
Process E	Buffer pH 5.5	117	14.2	2.3*	2.04 ± 0.09
Process F	H_2O	117	16.0	2.5–3	2.5 ± 0.20
Process G	H_2O	117	27.0	6–7	6.65 ± 0.15

* Minimal required F_0 value based on Pflug et al. (1985).

2.1.3. Thermal treatments

It has been shown previously that blanching carrot pieces at low temperature (typically 55–60 °C) prior to the actual thermal treatment results in a better texture retention compared to non-pretreated carrot pieces. If this low temperature blanching is followed by soaking the carrot pieces in a Ca^{2+}-solution, even less texture degradation can be observed after subsequent thermal processing (Sila, Smout, Vu, Van Loey & Hendrickx, 2005; Rastogi, Nguyen & Balasubramaniam, 2008). Therefore, in this pilot scale study, non-pretreated as well as pretreated carrot samples were subjected to the actual thermal process. The pretreatment comprised a blanching step at 60 °C for 40 min in a water bath, followed by Ca^{2+}-soaking.

This pilot scale study aimed at determining the effect of thermal treatments with different intensities on carrot textural and nutritional characteristics. Therefore, pasteurization as well as sterilization treatments were included in this study. Both for the pasteurization and sterilization treatments, mild and more intense conditions were considered. An overview of the different processes, ranked according to their intensity, is given in Table 1. The denomination of the processes (process A up to process G) will be further used when discussing the results. After the treatments, the glass jars containing the carrot pieces, were stored at 4 °C until analysis (the maximal shelf life was taken into consideration).

The least intense process, a mild pasteurization process (process value of ${}^{10\,°C}P_{70\,°C} = 2$ min) resulting in a 6 log reduction of *Listeria monocytogenes* (ECFF, 2006), ensures that the pasteurized carrot pieces (low acid food products) can be stored at 5 °C for maximally 10 days. The process was performed at 70 °C. The more intense pasteurization process (process value of ${}^{10\,°C}P_{90\,°C} = 10$ min) leads to a 6 log reduction of non-proteolytic *Clostridium botulinum* spores (ECFF, 2006; Silva & Gibbs, 2010), ensuring that the pasteurized carrot pieces can be stored at 5 °C for up to 6 weeks. The process was performed at 90 °C. For sterilization processes, Pflug, Odlaug and Christensen (1985) listed the minimal required F_0 values as a function of the pH for low acid food products. In our study, the pH of the carrot pieces was adjusted by changing the pH of the brine: acetate buffer solutions of different pH values were used and sterilization processes resulting in the minimal required F_0 values were performed (three different pH levels and hence three sterilization intensities were considered). It is generally recognized that a sterilization process with an F_0 value of 2.5–3 min, resulting in a 12 log reduction of proteolytic *Clostridium botulinum* type A spores, is adequate to produce shelf